

FY14 Center Innovation Fund (CIF)/Director's Innovation Fund (DIF): Step-1 Proposal

SECTION 1

Principal Investigator: Sean Swei, Ph.D.

Ames Code: TI

Proposal Title: Guidance and Control Architecture Design and Demonstration for Low Ballistic Coefficient Atmospheric Entry

Proposal Category: (please check at least one):

Center Innovation Fund ☒ Director's Innovation Fund ☐

FY14 CIF/DIF Focus Areas (please check all that apply):

- ☒ 1) (CIF Only) High-level of inter-center collaboration
- ☒ 2) Significant use of Ames SpaceShop
- ☒ 3) Aligns with Flight Opportunities Program
- ☒ 4) Aligns with National Initiative
- ☐ 5) (DIF only) Aligns with Center Core Research Areas

Hypothesis to be tested (DIF Proposal Only):

Proposal Approval:

Proposers must inform their Branch and/or Division managers about their CIF/DIF proposals for concurrence on the strategic value, availability of labor resources, and proposal-development support.

☒ TI Branch manager has been informed of this proposal and concurs with its submission. TI Branch Manager name: Kalmanje S. Krishnakumar, Ph.D.

☒ TS Division manager has been informed of this proposal and concurs with its submission. TS Division Manager name: Dean Kontinos, Ph.D.

☒ RE Branch manager has been informed of this proposal and concurs with its submission. REE Branch Manager name: Kuok Ling

SECTION 2

2.1 Science/Technical Objectives:

2.1.1. Objectives: We propose to develop an active guidance and control (G&C) system for the ADEPT (Adaptable Deployable Entry and Placement Technology) entry vehicle for Aerocapture and Entry, Descent and Landing (EDL) missions with large payloads. This is a game changer and will allow extending the current investment beyond simple *ballistic* entry to accomplish *lift guided* entries, including Aerocapture at Venus, Mars and other destinations. The ADEPT concept utilizes a mechanically deployable aeroshell with a flexible carbon fabric, a multi-functional element that is drag generating decelerator and thermal protection system, for planetary entry. The goal of proposal, which has never been done, is to utilize ADEPT aeroshell as a controllable G&C effector through innovative aerosurface actuation concepts and real-time optimization based control methods for planetary entry maneuvers.

2.1.2 Current state-of-the-art: The Game Changing Technology program is currently supporting design, manufacture and ground-based verification of a full-scale, 6-m diameter, ADEPT vehicle suitable for *ballistic unguided entry* of a Venus lander. The low ballistic coefficient of the ADEPT vehicle configuration combined with mechanically articulated aeroshell is a *game changer* and the G&C aspects of the *lift guided planetary entry have never been explored*.

2.1.3 Technical challenges: The proposal addresses the three main areas of G&C technical challenges: **1) Venus aerocapture.** The upper atmosphere density profile is not sufficiently characterized and this makes targeting to a planned orbit specially challenging. A real-time onboard optimal G&C algorithm and guided lift/drag modulation are required to manage the aerocapture trajectory. **2) Precision landing at Mars with hypersonic/supersonic entry and power descent.** For ADEPT vehicle, since the aeroshell remains part of the landed system, additional dynamical complexity needs to be accounted for due to the motion of aeroshell, and the coupling between aeroshell motion and vehicle dynamics further complicates the G&C problem. The set of reachable states, including hazard/obstacle avoidance, via controllable aeroshell needs to be quantified. **3) Development of lift guided mechanisms for ADEPT aeroshell.** Given the mission requirements/flight conditions, a viable and effective actuation mechanism to control the ADEPT aeroshell needs to be designed and analyzed.

2.1.4 Relevance of proposal: The proposed research aligns well with the three technical areas in the Space Technology Roadmaps, they are: TA09 Entry, Descent and Landing; TA04 Robotics and Autonomous Systems; and TA12 Materials, Mechanical Systems and Manufacturing. They have identified “sample return, autonomous G&C, deployable hypersonic decelerators” and “innovative, multifunctional, lightweight concepts” as game changing technologies for planetary entry missions. The proposal also addresses all of CIF Focus Areas: 1) The proposal leverages on existing collaboration with researchers of other centers and academia. Letters of support/advocacy from LaRC, GSFC, APL, and ADEPT Project Manager; please see Appendix B, indicated that the proposed G&C research complements to their efforts in Venus aerocapture mission and contributes significantly to the Advancement of Exploration Class Human Mars Missions. In particular, the EDL Principal Investigator Michelle Munk advocates that the product of proposed research should be included in the future System Architecture trade studies; 2) Ames SpaceShop facility will be utilized to develop hardware test article for bench and (*optional*) wind tunnel tests; 3) The planned wind tunnel testing at subsonic facility may not provide the characteristics of high velocity effects, however the goal is to demonstrate the efficacy of the proposed aeroshell control concepts and show the validity of the process. Successful ground testing will then serve as a pathfinder for operational demonstration of a scaled-down guided ADEPT vehicle in suborbital testing under the Flight Opportunities Program; 4) The National Robotics Initiative identifies the precision landing capability near a scientifically interested target highly desirable and poses a great technical challenge.

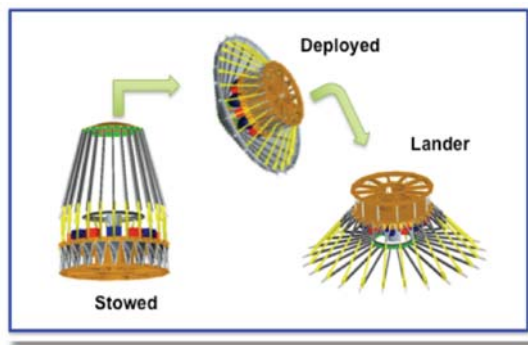


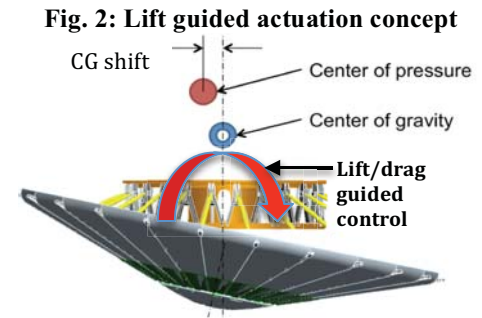
Fig. 1: ADEPT configuration at various flight conditions (Note: Carbon fabric covering the structure not shown)

2.2 Innovation:

2.2.1 Innovation of proposed research: The proposal aims to design and implement an innovative lift vector control system so as to generate aerodynamic forces and moments needed for *guided* planetary aerocapture and precision EDL missions at Mars and Venus using the low ballistic coefficient concept ADEPT. The revolutionary aspect of the proposed research is that such active control methods with deployable aerosurface for large payload systems have never been demonstrated beyond conceptualization. The key enabling technology behind this new approach is the advanced real-time convex optimization based G&C methodology specifically tailored for planetary entry vehicle with controllable aeroshell. The proposal also leverages on the existing ADEPT platform and lessons-learned from developing the control system for a 2-m diameter ADEPT Ground Test Article (GTA), which has just successfully demonstrated the first phase of aeroshell deployment test. These offer a solid foundation for successful development of *active lift/drag guided control* methods for ADEPT and allow New Frontier and Discovery mission proposers to achieve science goals otherwise unachievable.

2.2.2 Technical approaches/expected results: The proposed research focuses on the following four main tasks. **1) Actuation mechanism design for ADEPT aeroshell:** The concepts for aeroshell actuation are based on controlling the position of either *center-of-gravity* (CG) or *center-of-pressure* (CP), so as to generate guided lift for aeroshell. Three potential actuation architectures will be investigated: a) RCS thrusters; b) active ballast; and c) gimbaled articulation. These actuation concepts can be combined with either *symmetrical* or *asymmetrical* aeroshell. **2) Development of control centric dynamic models:** In addition to the 6-DOF physics-based vehicle model, we will incorporate the coupled aerodynamic effects to describe vehicle dynamics during aerocapture and EDL. **3) Controllability analysis:** For hypersonic entry and aerocapture, the goal is to quantify the set of all reachable planetary orbits as a function of entry conditions and vehicle properties. For power descent using RCS, lift/drag modulation of aeroshell can be utilized to minimize the trajectory errors subject to constraints on fuel burn. In summary, the G&C component at each mission scenario will be developed and the quantification of the controllability will be based on the recent breakthroughs on *constrained reachability analysis* of control systems operating in complex environments. **4) Scaled ADEPT model development:** After the preferred actuation architecture has been selected, a scaled prototype of ADEPT model will be built for bench testing and (*optional*) wind tunnel evaluation, to characterize the structure/mechanical and aerodynamic properties.

2.2.3 Near and long term impact for NASA: The 6-m full scale ADEPT development in the next 3 years aims to enable New Frontier (NF) Class Venus missions. Addition of RCS to the 6-m ADEPT, if the proposed research proves it as an attractive next step, can enable aerocapture missions at Venus, which can be proposed in the next NF proposal cycle as both an orbiter and a lander. The current STMD plans are to start assessing technologies that can be integrated for Human Mars and Heavy Mass Mars mission beyond 2035 timeframe and this requires scaled flight demonstration at Mars in 2026 timeframe. Therefore, understanding the G&C challenges of ADEPT and developing scalable approaches in the next few years is essential for ADEPT to continue to be a viable option.



APPENDIX B: Letters of Support/Advocacy

➤ NASA Langley Research Center (LaRC): Michelle Munk, EDL Principal Investigator

Subject: Advocacy for Ames CIF Proposal

Date: Sunday, October 27, 2013 8:47:41 PM Pacific Daylight Time

From: Munk, Michelle M. (LARC-D205)

To: Venkatapathy, Ethiraj (ARC-TS)

CC: Swei, Sean Shan-Min (ARC-TI)

Dear Raj,

I have read the draft version of the ADEPT Lifting / Aerocapture proposal to the Ames CIF. Among the many challenges of low ballistic coefficient deployables, the guidance and control aspect is one of the things we need to address if these concepts are to be used for Venus or Mars lifting or aerocapture missions. NASA has invested considerable time and limited resources to understand the challenge of guidance and control by shifting the CG using mass movement for inflatable concepts such as HIAD, but there are other methods. ADEPT, the alternate concept that STMD/GCDP is developing, is currently focused on non-lifting, ballistic entry only and lifting entry for direct entry or for aerocapture has never been investigated.

As you know, STMD/GCDP is looking at Human Mars Missions with both HIAD and ADEPT technologies to understand the challenges for integration and ConOps for emplacing a 40 mT payload at Mars. The effort proposed in the CIF draft proposal you sent me, if funded, would help us to understand and address the guidance and control aspects both for Venus and Human Mars missions. The product of the effort should be a deliverable that NASA could fold into future System Architecture studies when evaluating ADEPT as part of the technology trade space. Sooner or later, we will have to choose the system that will take us to Mars, and this will be critical information to have available.

Therefore, I endorse and advocate for this effort.

Best of luck,
Michelle

Michelle M. Munk
EDL Principal Investigator
Mail Stop 489
NASA-Langley Research Center
Hampton, VA 23681
Office: (757) 864-2314
Fax: (757) 864-4475
Cell: (757) 876-7761
Email: Michelle.M.Munk@nasa.gov

➤ **ADEPT Full Scale Demonstrator Project Manager: Paul Wercinski**

Subject: ADEPT project letter of support for Sean Swei's CIF proposal

Date: Tuesday, November 12, 2013 9:35:51 AM Pacific Standard Time

From: Wercinski, Paul F. (ARC-TSS)

To: Swei, Sean Shan-Min (ARC-TI)

CC: Venkatapathy, Ethiraj (ARC-TS), Gage, Peter J. (ARC-TS)[Neerim Corp.]

Dear Sean;

As project manager for the GCD funded project, Adaptable Deployable Entry and Placement Technology (ADEPT) Full Scale Demonstrator (FSD), I wanted to express my strong endorsement for you proposed CIF activity titled, "Guidance and Control Architecture Design and Demonstration for Low Ballistic Coefficient Atmospheric Entry". The ADEPT project is currently focused on near term mission infusion using a ballistic entry configuration. Your proposed effort in developing and demonstrating an ADEPT lifting capability is not only complimentary but it enhances the value of the ADEPT technology and successful options to deliver a direct payload via ballistic un-guided and an alternate that could lead to a lift guided aerocapture and entry not just at Venus, and also at Mars will allow the next Decadal Survey to think of missions that is not currently possible or conceived.

The ADEPT FSD project team has generated an aero-data base and we are willing to support mining the current data base and will support our Aero/Aerothermal lead (Dr. Dinesh Prabhu) to generate additional CFD simulations needed to enhance the database for your proposal should it go forward.

Also, it is my expectation that the ADEPT Principal Technologist (Dr. Ethiraj Venkatapathy) will monitor the proposed CIF effort and advocate for either incorporating developments in the CIF proposal in the existing ADEPT project or for potential future GCD activities as a new start.

Best regards,

-Paul

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Paul F. Wercinski
 Manager, ADEPT Full Scale Demonstrator Project
 M/S 229-3
 NASA Ames Research Center
 Moffett Field, CA 94035
 Office: 650-604-3157
 Cell: 650-776-9984
Paul.F.Wercinski@nasa.gov

➤ **NASA Goddard Space Flight Center (GSFC): Lori Glaze, Deputy Director**

Subject: RE: Center Innovation Funds Proposal - ADEPT Lifting - GN&C Focus

Date: Tuesday, September 24, 2013 9:35:06 AM Pacific Daylight Time

From: Glaze, Lori S. (GSFC-6900)

To: Venkatapathy, Ethiraj (ARC-TS)

CC: Gage, Peter J. (ARC-TS)[Neerim Corp.], Swei, Sean Shan-Min (ARC-TI), Garvin, James B. (GSFC-6000)

Dear Raj,

Thank you so much for stopping by my office yesterday to tell me about your Center Innovation Fund proposal concept to develop ADEPT lifting capability. ADEPT, combined with the focus on Guidance, Navigation and Control, has tremendous potential for planetary missions. As you know, I have a particular interest in missions to Venus. Addition of a lifting capability would enable the insertion of an in situ payload into the upper Venus atmosphere, above the cloud level. This would allow key atmospheric measurements that have never been made before. Further, the lifting capability may also open up opportunities for aerocapture, which is of interest for possible future missions requiring orbit insertion.

I am a big fan of the ADEPT technology! GSFC has demonstrated support for ADEPT over the last two years through my collaborative IRAD project to develop ADEPT - VITaL. We are also looking forward to continuing that collaborative relationship as GSFC supports the FY14 New Start for the 6m ADEPT Prototype project. I am definitely interested in the new ADEPT Lifting capability and look forward to continued partnerships as this new capability is developed!

Sincerely,

Lori S. Glaze

Deputy Director

Solar System Exploration Division

301-614-6466

Lori.S.Glaze@nasa.gov

➤ **Applied Physics Laboratory (APL): Ken Hibbard, Mission Systems**

Subject: Re: Center Innovation Funds Proposal - ADEPT Lifting - GN&C Focus

Date: Monday, September 30, 2013 2:10:51 PM Pacific Daylight Time

From: Hibbard, Kenneth E.

To: Venkatapathy, Ethiraj (ARC-TS)

CC: Reed, Cheryl, Wercinski, Paul F. (ARC-TSS), Peter Gage, Swei, Sean Shan-Min (ARC-TI), Glaze, Lori S. (GSFC-6900)

Dear Raj,

Thank you so much for keeping me informed about your Center Innovation Fund proposal concept to develop ADEPT lifting capability. ADEPT, combined with the focus on Guidance, Navigation and Control, has tremendous potential for planetary missions. As you know, we are very interested in this developing technology and the missions it may enable. Further, the lifting capability may also open up opportunities for aerocapture, which is of interest for possible future missions requiring orbit insertion.

APL looks to continue our relationship and support related to this effort, and is happy to have some of our Civil Space staff work with your team, attend various meetings, and help provide end-user focus. We are looking forward to continuing our collaborative relationship with the FY14 New Start for the 6m ADEPT Prototype project. I am definitely interested in the new ADEPT Lifting capability and look forward to continued partnerships as this new capability is developed!

Sincerely,

Kenneth Hibbard

Mission Systems Engineer

Assistant Group Supervisor

SEA Group, Space Department

JHU Applied Physics Laboratory

11100 Johns Hopkins Rd., Office 200-E570

Laurel, MD 20723-6099

Phone: 443-778-1458 (Baltimore) 240-228-1458 (Washington D.C.)

Cell: 443-463-3924

Email: Kenneth.Hibbard@jhuapl.edu